Nwp

DRILL PIPE CORROSION CONTROL USING AN INERT DRILLING FLUID

B. C. Caskey and K. S. Copass
Sandia National Laboratories

United States

ABSTRACT

The results of a geothermal drill pipe corrosion field test are presented. When a low-density drilling fluid was required for drilling a geothermal well because of an underpressured, fractured formation, two drilling fluids were alternately used to compare drill pipe corrosion rates. The first fluid was an air-water mist with corrosion control chemicals. The other fluid was a nitrogen-water mist without added chemicals. The test was conducted during November 1980 at the Baca location in northern New Mexico.

Data from corrosion rings, corrosion probes, fluid samples and flow line instrumentation are plotted for the ten day test period. It is shown that the inert drilling fluid, nitrogen, reduced corrosion rates by more than an order of magnitude. Test setup and procedures are also discussed.

Development of an onsite inert gas generator could reduce the cost of drilling geothermal wells by extending drill pipe life and reducing corrosion control chemical costs.

DISCLAIMER

INTRODUCTION

Sandia National Laboratories (SNL) manages the Geothermal Drilling and Completion Technology Development Program for the Division of Geothermal Energy (DGE) in the U.S. Department of Energy (DOE). The near-term goal of the program is to develop the technology required to reduce the cost of drilling and completing geothermal wells by 25% by 1983.

A major contributor to the high cost (4-5 times higher than a comparable oil or gas well) of geothermal wells is extensive corrosion of drill pipe--principally caused by oxygen present in the drilling fluid. Since a low density drilling fluid must be used when drilling in the typically underpressured geothermal reservoirs, air drilling techniques are commonly used. Water is usually injected into the air stream to aid cuttings removal. The combination of aerated water, high temperatures, and high velocities results in rapid drill pipe corrosion leading to pipe downgrading or premature failure. The controlling chemical reaction is

$$2Fe + O_2 + 2H_2O \rightarrow 2Fe(OH)_2. \quad (1)$$

Existing corrosion control techniques include adding caustic soda (NaOH) to raise the pH of the water to about 10 or 11. This provides excess hydroxyl ions that tend to drive the corrosion reaction to the left. Another technique for hot geothermal wells is to inject Unisteam [1], a high molecular weight amine resin that polymerizes at about 120°C (250°F) to form a viscous, water insoluble, oily coating. For protection of lower temperature sections of the drill string ammonium hydroxide (NH_4OH) is injected which condenses on the pipe to form a protective coating. Both of these latter techniques are aimed at preventing the cathodic reaction on the steel surface.

Removal of oxygen from the system has been proposed as another technique to control corrosion. Oxygen scavengers (ammonium bisulfite, for example) have been used for mud drilling but are not practical when large quantities of air are needed. Therefore, a test was conceived that would involve substituting an anerobic gas for air to evaluate the corresponding change in corrosion rates. Since unknown amounts of oxygen would be introduced into system each time a joint was added and during each drill pipe trip, a field test was the only method available to establish overall representative corrosion rates.

With the cooperation of Union Geothermal Company of New Mexico, a subsidiary of Union Oil Company of California, a field test was planned [2]. Using Brinkerhoff Signal Rig 78, under contract to Union, on Baca Well 22 in the Redondo Creek Field at the Baca Location in Sandoval County of northern New Mexico, USA, the test was performed early in November 1980.

TEST SETUP

Drill Site -- A diagrammatic drill site layout is provided as Figure 1. It also defines the location of monitoring and sampling points installed for this test. Not shown on the diagram is a separate return line from the wellhead to a separator. A recurring problem during the test was insufficient flow through the instrumented blooie line.

Data Collection -- A complete description of the data collection system may be found in references [2] and [3].

Data are available from the following sources:

1. Corrosion rings and coupons
2. Corrosometer readings - see Table 1 for locations
3. On-site liquid sample analyses - see Table 2 for sampling accomplished
4. Flow line instrumentation - see Table 1 for a listing and definition of locations.

Detailed test results from these four sources are presented later in this paper.

Data are not presently available from the following sources:

1. Drill pipe inspection - twenty-four joints of new drill pipe were thoroughly inspected before the test. Six joints (3 at the top and 3 at the bottom of the drill string) were used during each test phase. The post-test inspection has not yet been performed.

2. Complete sample analyses - these analyses currently are underway at three locations.

3. Corrater data - evaluation of these data is underway at both Sandia and Union Research.

Final results will be presented in reference [3].

TEST PROCEDURE

The test was started on November 6, 1980; previously the well was drilled to a depth of 971 m (3185 feet). Casing (245 mm/9-5/8 inch) had been cemented to 914 m (3000 feet). A 222 mm (8-3/4 inch) hole was drilled during the test with 114 mm (4-1/2 inch), 24.7 kg/m (16.6 lb/ft), Grade E drill pipe.

Figure 2 shows all the activities associated with the drilling. It also defines the test phases and shows well depth versus time. Some significant features of each test phase are:

Phase 1 - Treated aerated water drilling fluid
6 short reaming operations

2 drilling bit runs
2 coring bit runs
400 m (1315 feet) drilled
131.5 hours duration

Phase 2 - Nitrogen and water drilling fluid
2 short reaming operations
3 drilling bit runs
458 m (1500 feet) drilled
74.8 hours duration

Phase 3 - Treated aerated water drilling fluid
1 short coring bit run
3 m (10 feet) drilled
19.5 hours duration

For reference, both the phase definition dashed lines and the well depth data, as shown on Figure 2, will be plotted on all subsequent test data figures.

Practically all the drilling was through Bandelier Tuff. The test was stopped at a depth of 1832 m (6011 feet), near the top of the Paliza Canyon Andesite formation. The well showed evidence of producing geothermal energy during the first bit run of phase 2 at about 1500 m (4900 feet). Before that time, the well was considered atypically cold.

At the end of phase 1, the reserve pit and suction tank were drained and refilled with fresh water. This was accomplished to maintain the suction water at the following alkalinity values:

Phase 1 - pH between 10 and 12
Phase 2 - pH between 8 and 9
Phase 3 - pH between 10 and 12

The test was completed on November 16, 1980.

TEST RESULTS

Corrosion Rings and Coupons -- A total of 24 rings were installed inside the drill pipe at tool joints and 6 coupons were installed in recesses outside the pipe. However, 2 of the external coupons were damaged during removal and one was inadvertently left on the rig floor so that only three provided weight loss data. However, subsequent analysis of these three coupons revealed unexpected difficulties and their corrosion rate data are insufficient and unreliable. It was decided to not include their results in this presentation; they are shown only on Figure 3, which displays 27 data points for coupons and rings.

Also plotted is a line representing a uniform corrosion of 0.58 μm (23 microinches). Data points that fell below this line were arbitrarily ruled to have too little corrosion to provide reliable data. A disparity was discovered between the corrosion rates of two rings that were installed two feet apart (at each end of the crossover sub). The ring with the higher corrosion rate was felt to be representative of the true rate and subsequent laboratory tests [at 60°C (140°F) for 5 days] showed that the drill pipe thread lubricant used on Baca 22 does protect rings from corrosion. Therefore, ring 7838 (identified on Figure 3) is not considered further.

The surviving data are presented in Table 3 and plotted in Figure 4. These data show that corrosion is more severe near the bottom of the drill string and that the phase 2 rates were at least an order of magnitude (one cycle on the log plot) lower than those of phase 1. Phase 3 included less than 6 hours of circulating time, the remaining time was spent tripping or waiting; this data should be considered less reliable than that from the other phases.

Additional evidence of the effectiveness of an anerobic drilling fluid is provided by examining the corrosion rings. Figure 5 shows a direct comparison of two rings exposed for comparable times to each of the drilling fluids at the bottom of the drill string. The measured corrosion rates differ by a factor of 36 and the phase 1 ring shows numerous shallow pits. Photographs of all the rings and coupons will be included in reference [3].

Corrosometer Data -- Corrosometer probes were installed in the standpipe and the blooie line. These probes operate on the principle that the electrical resistance of a conductor increases as its cross sectional area decreases. Probes are built with an element whose resistance increase as it is exposed to corrosion. Since the probes have a finite life, a new probe was installed in the standpipe for test phases 2 and 3. All the probes used a flush element that was mounted slightly below the inside surface of the flow line.

The standpipe corrosometer data is presented in Figure 6. Since the probes measure average rates over the time between readings, a bar is plotted which represents the average rate for each test phase. All the intermediate readings are also plotted as thin lines. Phase 1 data exhibit a fairly uniform rate dropping to about 2.5 mm/y (98 mpy), a rate consistent with the upper corrosion ring measurement. Phase 2 data shows a high initial rate with the final value about 0.07 mm/y (3 mpy), again in agreement with the ring data. Although only two readings were taken during phase 3, the corrosometer and upper ring data are comparable.

The blooie line corrosometer data are shown in Figure 7. Although a similar pattern is observed as for the standpipe corrosometer, the readings are about a factor of ten lower. It is estimated that only about 10 percent of the return line flow intermittently came out the blooie line, which could explain the lower readings. This data does provide additional evidence for the effectiveness of nitrogen as a drilling fluid.

Sample Analyses -- Samples were taken periodically and the oxygen content and pH levels were measured on the liquid samples, after appropriate cooling. See reference [3] for a complete description of the procedure and equipment; the results of these analyses are presented here. Figures 8 and 9 show the alkalinity of the water line liquid and the blooie line liquid respectively. Both plots show that the pH was lower (as planned) during phase 2 and that pH tends to drop as each bit run progresses.

Figure 10 presents the oxygen in the water line. Although it was expected to vary inversely with the water temperature (presented later as Figure 16), this effect is not obvious from the data, however the second bit run of phase 2 does show this trend.

The primary reason for the reduced corrosion during phase 2 is presented in Figure 11. During phase 2 bit runs, the oxygen content in the blooie line liquid dropped to a few tenths of a part per million. Since the equilibrium concentration of dissolved oxygen in water with nitrogen at typical downhole conditions is about 40 ppb, the effect of tripping and adding joints appears to raise oxygen levels to those measured.

<u>Flow Line Instrumentation</u> -- Subsequent data plots (Figures 12 through 18) were made from data stored in digital format on a magnetic tape. Data were recorded every five minutes; each plot contains more than 1500 points. When all of these points are presented on one plot, most of the data look noisy. However, when expanded to one day at a time, these noisy points are accurate and represent flow line conditions when a joint of pipe is added. A "noisy" point, therefore, may occur every 30-40 minutes or one point in 6 or 7.

Also evident on the plots is a 14-hour data gap on November 7 when the tape recorder was mistakenly left off. Not as evident is questionable data toward the end of November 15 when many instrumentation lines froze.

The flow rate of air (phases 1 and 3) and nitrogen (phase 2) is shown in Figure 12. During the first bit run of phase 1, both air compressors were used and provided about 1.04 m^3/s (2200 SCFM) flow rate. Subsequent bit runs of phase 1 and phase 3 saw only one compressor used which provided about 0.52 m^3/s (1100 SCFM) of air. The data on Figure 12 are not considered completely accurate until late on November 9 when calibration problems were resolved. Nitrogen was provided during phase 2 by a pump/vaporizer truck supplied with liquid nitrogen from an air separation plant. The rate at which nitrogen was supplied was comparable to one air compressor's capability.

Water flow supplied by the mud pumps as a function of time is plotted in Figure 13. Between 15 and 25 x 10^{-3} m^3/s (240 to 400 gpm) of water was pumped most of the time.

Chemicals were injected in the air line during phases 1 and 3. Since the flow rate was fairly constant at about 125 x 10^{-6} m^3/s (2 gpm) and the chemical concentrations were changed between phase 1 bit runs, the plot shows only the amounts of chemicals used. Included are Unisteam, ammonium hydroxide and H35 surflo scale inhibitor.

Figure 15 presents the pressure in the standpipe. This data is representative of the data recorded for air/nitrogen pressure, water line pressure and chemical injection pressure since all lines are fed to the standpipe. About 2 MPa (290 psia) pressures were typical. Although when two compressors were used, or when coring, the pressures increased considerably.

The temperatures measured in the water line are presented in Figure 16. As drilling progressed, the water was heated by liquid returns. During the times that water was not flowing (non-circulating times on Figure 2), the temperature probe measured static water temperature which tended to cool to ambient temperature.

Figure 17 presents the temperature measured in the flow line. Since the blooie line was active only part of the time, these data are not representative of the returns' temperature. However, the geothermal fluids encountered late on November 12 are evident.

The final plot (Figure 18) shows the pressures measured in the blooie line. From this plot the times that the blooie line was flowing are evident. The ambient pressure at the drill site was about 69 kPa (10 psia). Flow is characterized by an increase in pressure above ambient.

CONCLUSIONS

This test demonstrated that severe drill pipe corrosion problems can be reduced by use of an anerobic drilling fluid. The cost of corrosion controls during phase 1 and 3 of this test were estimated at $3000/day. When the cost of drill pipe loss (perhaps $1000/day) is added, the total corrosion costs are about $4000/day. Although nitrogen for this test cost about $17,000/day, on-site generation of an anerobic gas is expected to be possible for about $2000/day. Sandia National Laboratories is pursuing the development of an on-site generator. Two approaches are being pursued: (1) cleaned up gas from diesel exhaust and (2) a portable cyrogenic air separation unit. Another field test will probably be performed when a full scale gas generator is available.

REFERENCES

[1] Pyle and Fischer, US Patent No. 3,749,554.

[2] Billy C. Caskey and K. S. Copass, Geothermal Drill Pipe Corrosion Test Plan, SAND80-1090 (Albuquerque: Sandia National Laboratories, December 1980).

[3] Billy C. Caskey and Kathleen S. Copass, Geothermal Drill Pipe Test Results, SAND80-2810 (Albuquerque: Sandia National Laboratories, in preparation).

Table 1

Flow Lines Instrumentation

Location	Type	Recording	Remarks
Air/Nitrogen Line (point Z)	Pressure	12 per hour	
	Temperature	12 per hour	
	Flow Rate	12 per hour	
Standpipe (point B)	Pressure	12 per hour	
	Temperature	12 per hour	
	Corrosometer	see note	corroding strip probe
	Corrater	12 per hour	linear polarization resistance probe
Blooie Line (point C)	Pressure	12 per hour	
	Temperature	12 per hour	
	Corrater	12 per hour	linear polarization resistance probe
	Corrosometer	see note	corroding strip probe
Water Line (point D)	Pressure	12 per hour	
	Temperature	12 per hour	
	Flow Rate	12 per hour	
Chemical Injection Line (point A)	Mass Flow Rate	12 per hour	only active when using air
	Pressure	12 per hour	
	Temperature	12 per hour	

Note: The corrosometers were read with a portable instrument at appropriate intervals.

Table 2

Sampling Accomplished

Sampling Point	Scheduled Timing	Actual Quantity	Analyses Required
Blooie Line Instrumentation Spool (point C)	When drilling nears the end of of every pipe joint and the blooie line is flowing.	47	Gas Sample -- O_2, CO_2, N_2
		48	Liquid Sample* -- pH, Cl^-, Ca^{++}, SO_4^{--}, CO_2, H_2S, O_2, NH_3, total dissolved solids, Na, K, Ca, Mg, Li, F, Si, Ru, Cs, U, Fe, Sr, Al, S, As, B, Pb, Ag, Cu, W, Sb, Hg, Tl, Ba (100 to 250 cm^3 size)
		49	Solid Sample -- X-ray diffraction, X-ray fluorescence
Water Line Instrumentation Spool (point D)	When drilling nears the end of every second joint of drill pipe.	38	Liquid sample* -- pH, O_2, Na, K, Ca, Mg, Li, F, Si, Ru, Cs, U, Fe, Sr, Al, S, As, B, Pb, Ag, Cu, W, Sb, Hg, Tl, Ba (100 to 250 cm^3 size)
Nitrogen Line Instrumentation Spool (point Z)	When drilling nears the end of every 8th to 10th joint of drill pipe	7	Gas Sample -- O_2

*The pH and O_2 concentration were measured as soon as possible after collection (on site). Rapid cooling provisions were provided to make these measurements.

Table 3

Corrosion Ring Data

NUMBER	PHASE	LOCATION[1]	CORROSION RATE (mm/y)	(mpy)	EXPOSURE TIME (HOURS)	REMARKS
15519	1	Bottom	8.3	330.	39.2	Badly pitted, heavy scale
6299	1	Bottom	4.1	160.	66.8	Numerous pits, magnetite scale
6247	1	Bottom	6.0	240.	32.8	Shallow pitting, magnetite scale
6272	1	Bottom	11.4	450.	13.5	Pitting over outside edges
6287	1	Top	1.9	76.	105.0	Numerous shallow pits, magnetite scale
6284	2	Bottom	0.75	30.	46.7	Slight pitting, $CaCo_3$ ad magnetite scale
6275	2	Bottom	0.33	13.	46.7	Slight pitting, $CaCO_3$ and magnetite scale
7874	2	Bottom	0.13	4.9	74.8	Light pitting, some $CaCO_3$ and magnetite scale
7868	2	Bottom	0.11	4.4	74.8	Light etching, some scale
6281	2	Top	0.09	3.4	67.5	No pitting, slight $CaCO_3$ scale
7841	2	Top	0.11	4.3	73.0	Minute pitting, slight magnetite scale
18154	3	Bottom	2.7	108.	19.5	Pitting, magnetite scale
18155	3	Bottom	3.3	131.	19.5	Moderate pitting beneath magnetite scale
18159	3	Bottom	2.7	108.	19.5	Moderate pitting and heavy magnetite scale
18162	3	Bottom	1.9	73.	19.5	Pitting, heavy magnetite scale
18147	3	Top	0.39	15.	14.2	Etching, magnetite scale

Note 1: "Bottom" is defined as about 150 m (500 feet) above the drill bit; "Top" is defined as not more than 180 m (600 feet) below the Kelly at the top of the drill string. All rings were installed between a tool joint pin and box inside the pipe.

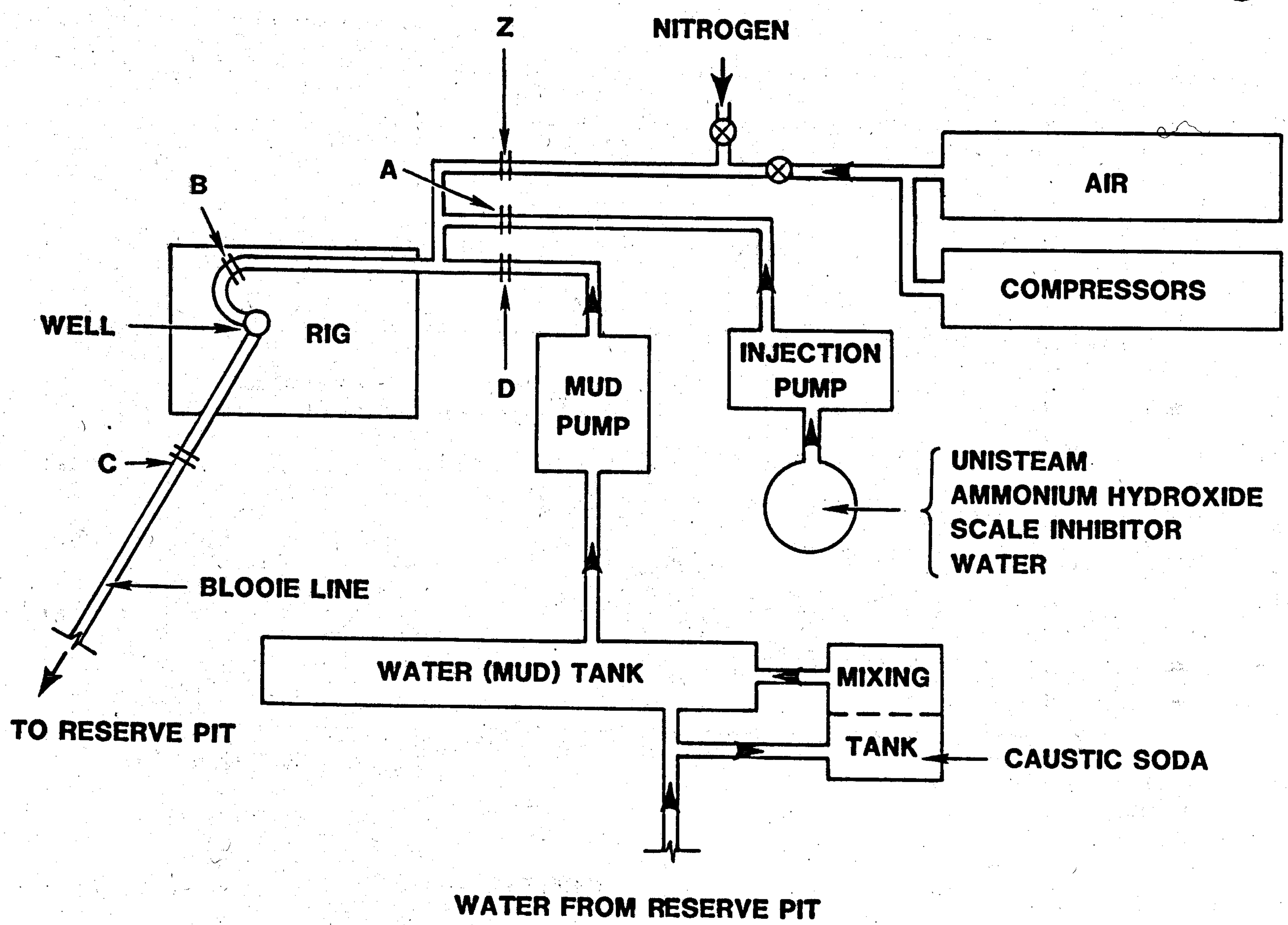


Figure 1. Diagrammatic Drill Site Layout and Monitoring Point Locations.

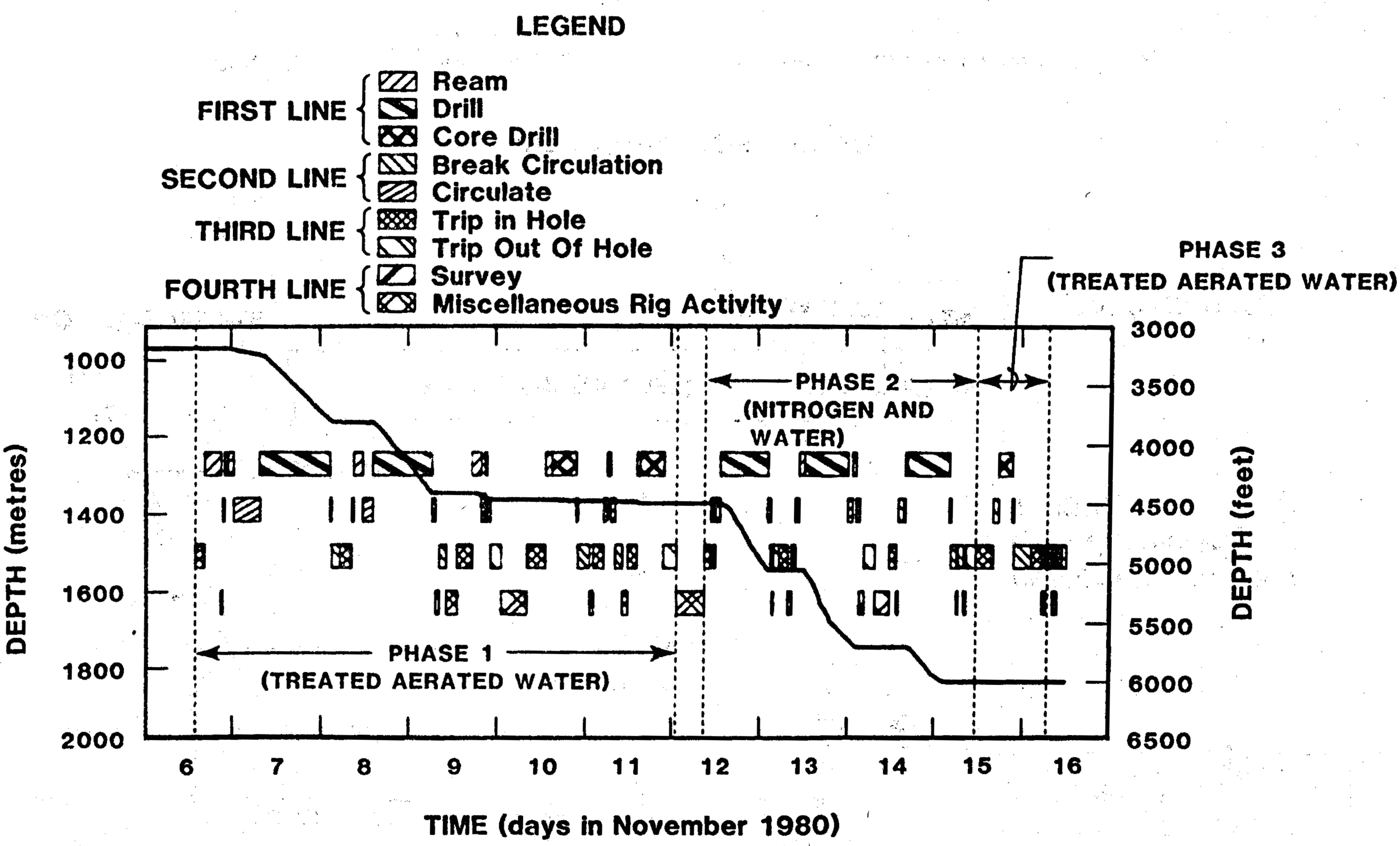


Figure 2. Rig Activities Versus Time and Well Depth. The activities related to drilling are broken out on the first line in the plot. The second and third lines are related to circulation and tripping respectively. The bottom line is related to other activities. The three test phases are also defined on the figure.

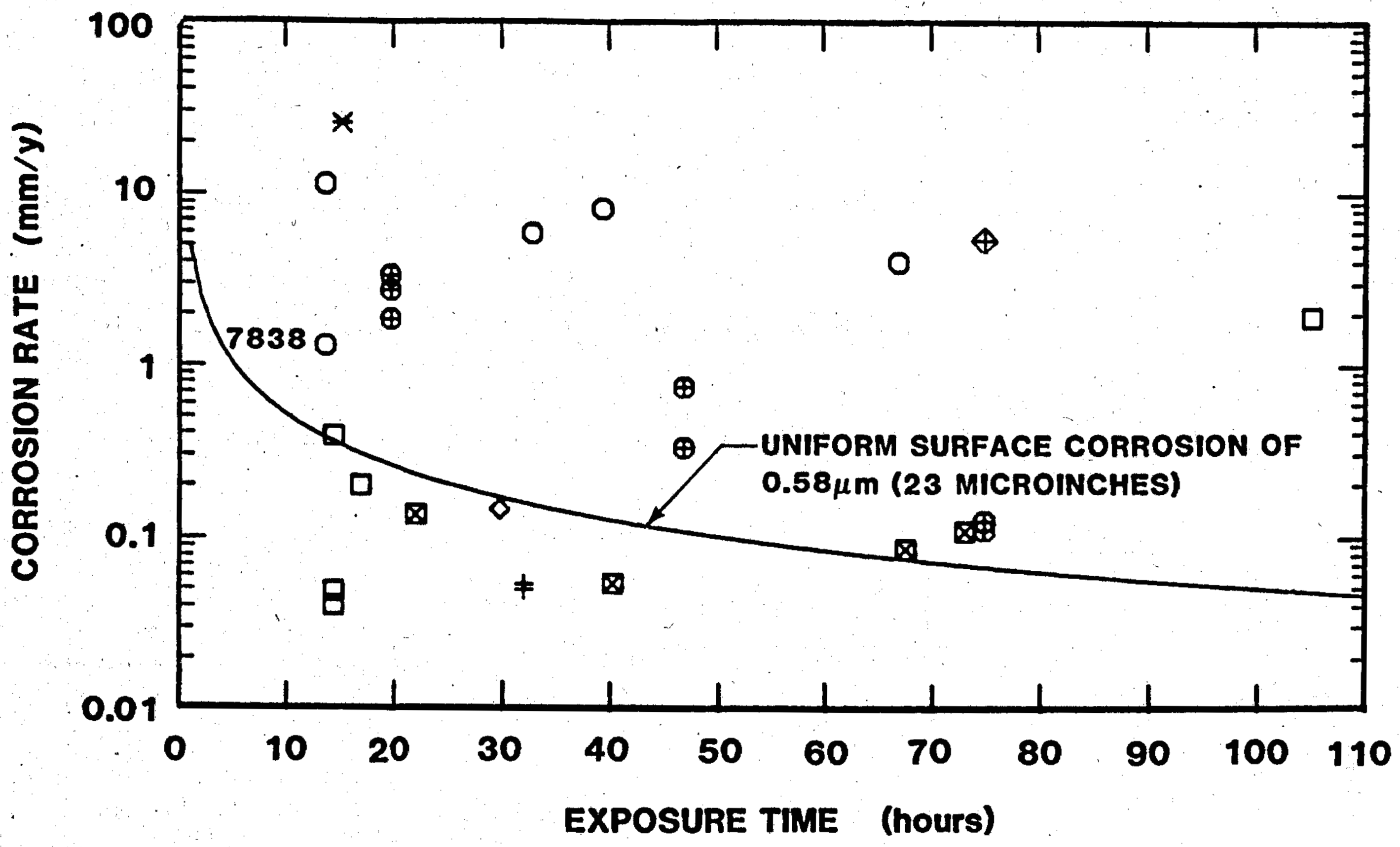


Figure 3. Corrosion Ring and Coupon Data. All the rings and coupons used during the test are plotted. The square and round symbols were rings near the top and bottom of the drill string, respectively. The symbols with internal markings represent those used during phase 2 (nitrogen). The diamonds and X's were external coupons and the +'s were rings that were inadvertently left in the derrick.

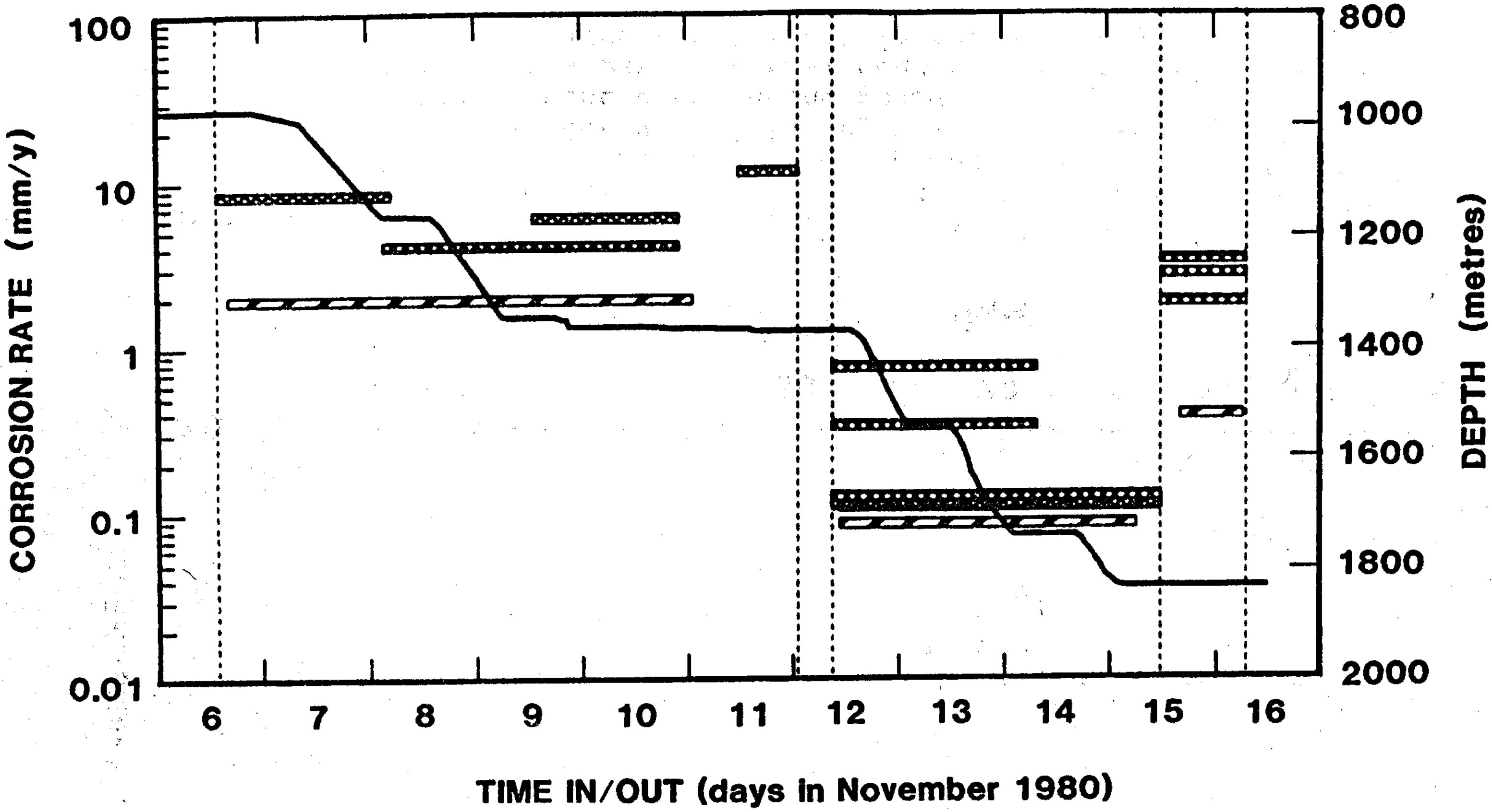
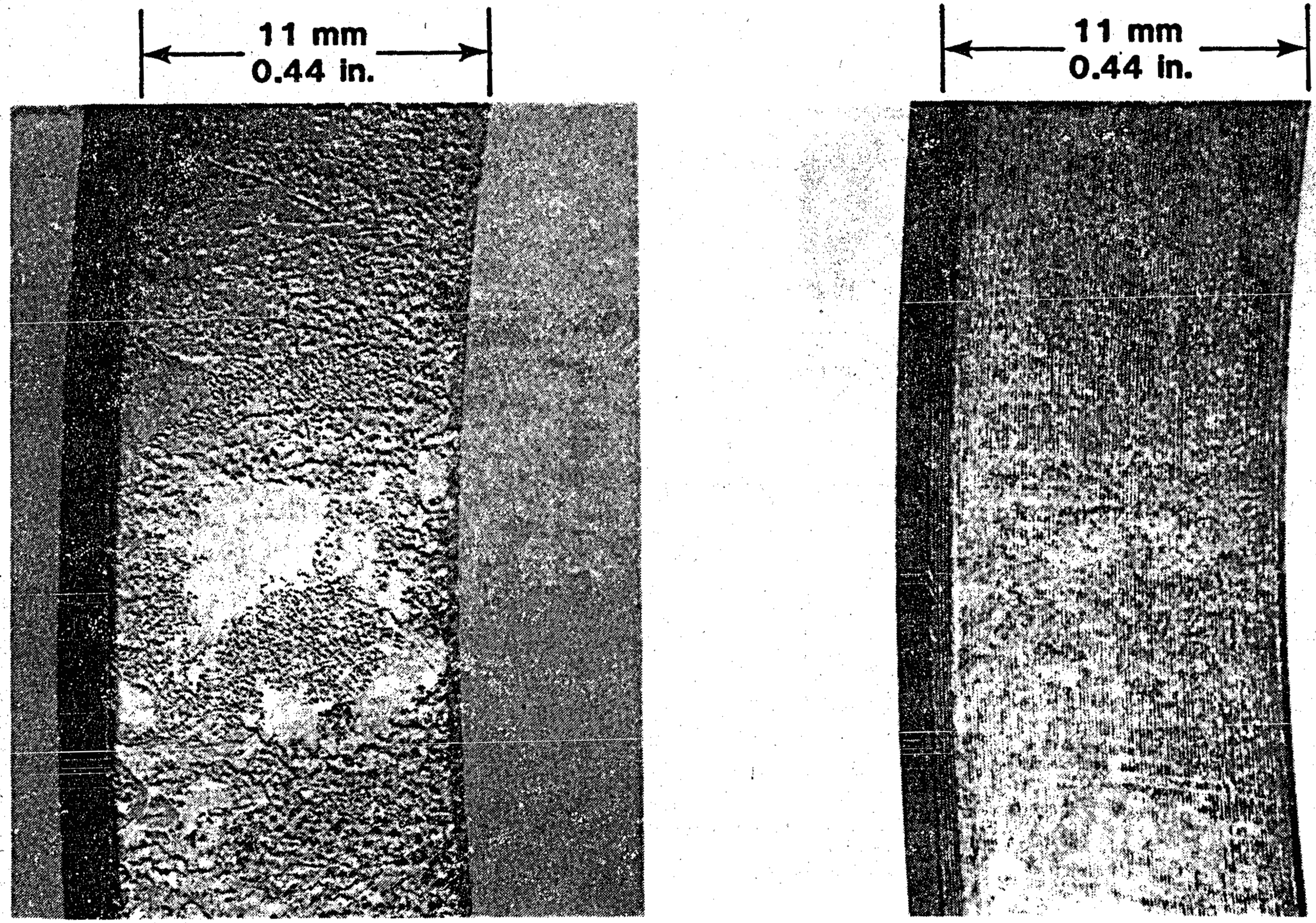


Figure 4. Corrosion Ring Data. Only rings that exhibited a weight loss corresponding to a uniform surface corrosion of more than 0.58 m (23 microinches) are plotted. These data are also shown in Table 3. The cross hatched bars represent rings installed near the bottom of the drill string; the barberpole bars represent those near the top of the drill string.



RING NO. 6299 **RING NO. 7868**

Figure 5. Corrosion Ring Comparison. The ring on the left was exposed during phase 1 to treated aerated water for 66.8 hours; its measured corrosion rate is 4.1 mm/y (160 mpy). The ring on the right was used during phase 2 (nitrogen and water) for 74.8 hours; its corrosion rate is 0.11 mm/y (4.4 mpy). Both rings were installed just above the drill collars about 150 m (500 feet) above the drill bit.

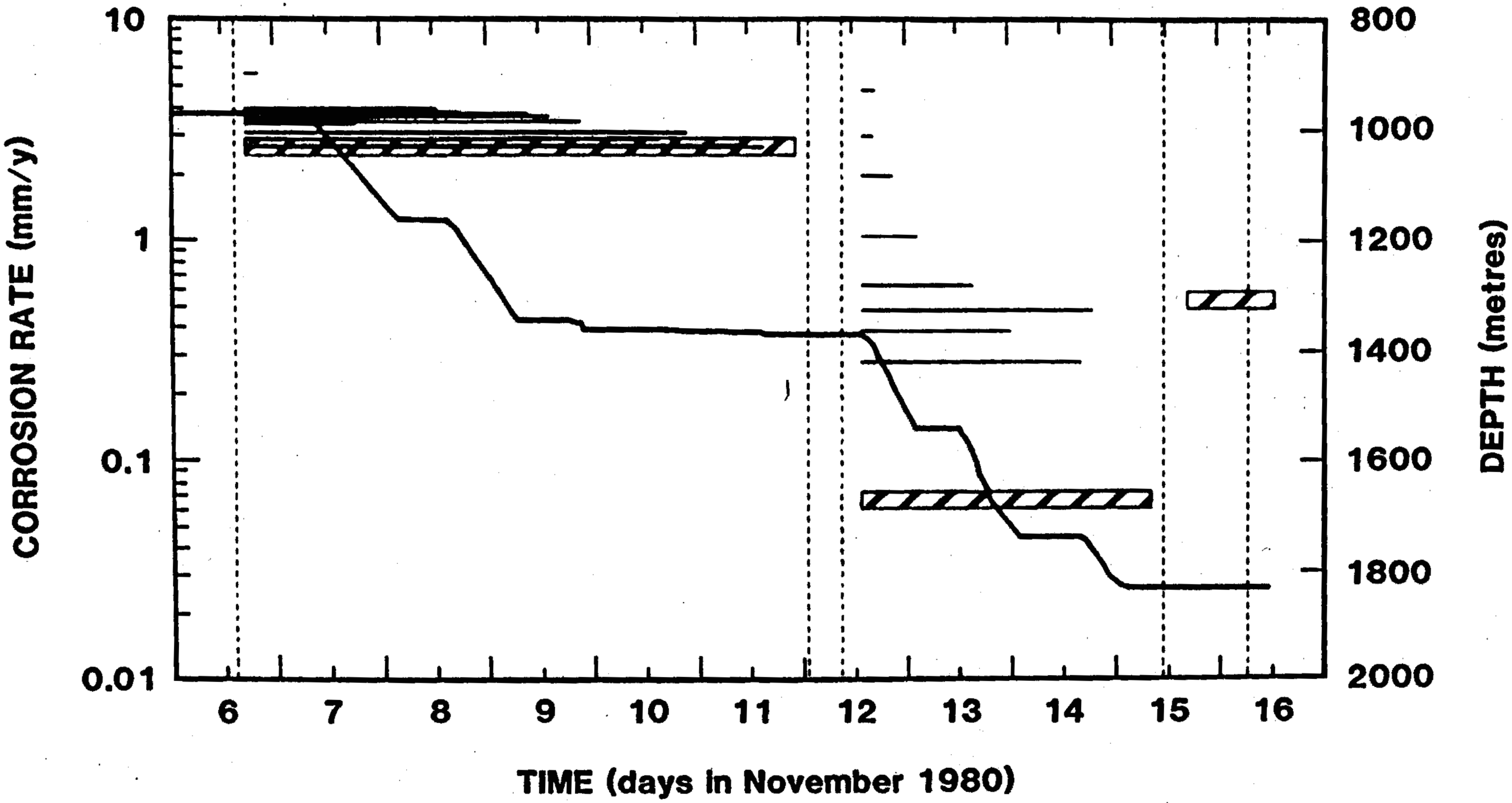


Figure 6. Corrosometer Probe Data from the Standpipe. Since these probes measure corrosion rate by a resistance change of a corroding element, the average rate for each phase is shown by the bar. Intermediate values are plotted to show rate changes as the test progressed.

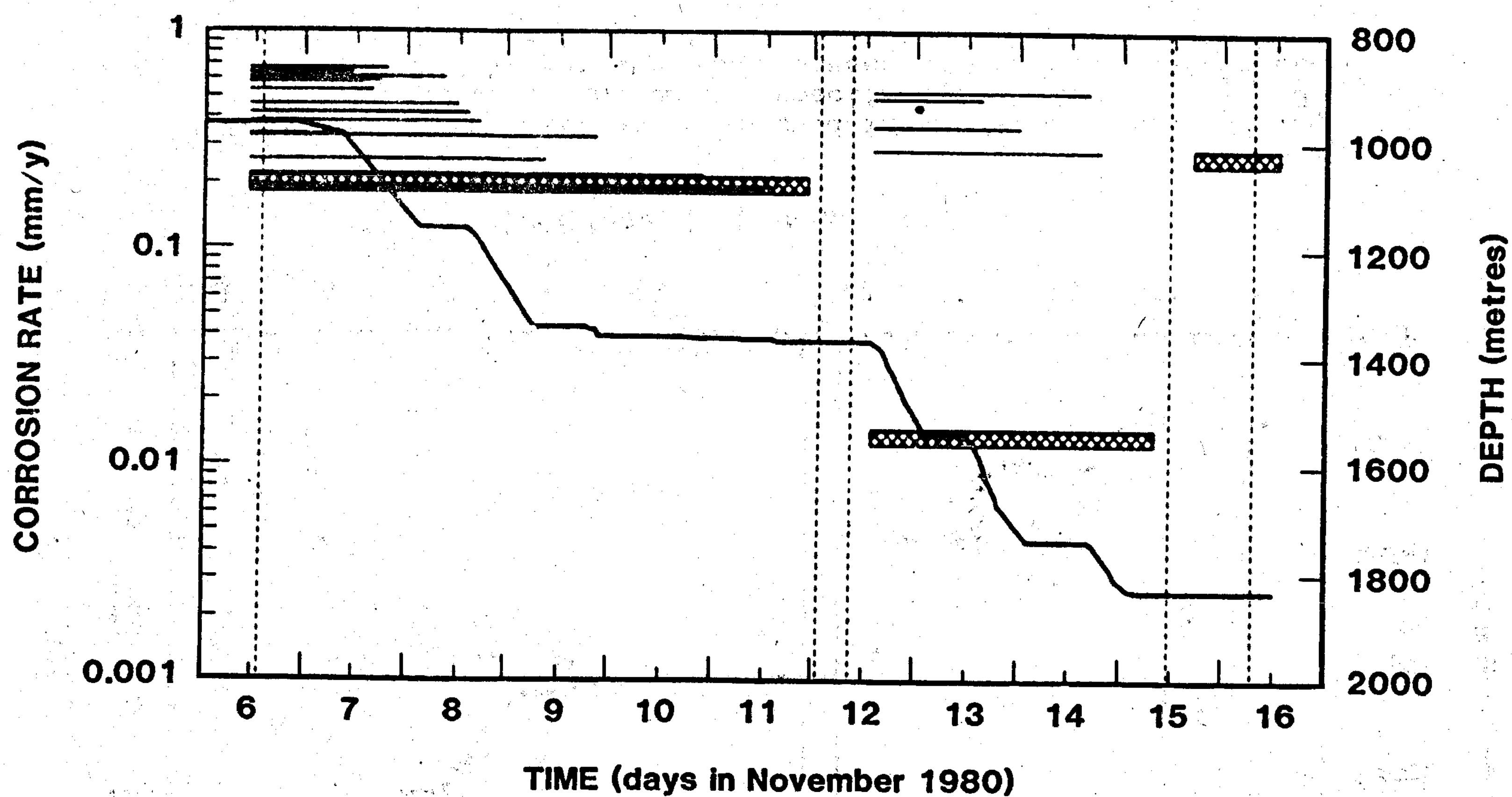


Figure 7. Corrosometer Probe Data from the Blooie Line. These data do not represent the average rates for the top of the drill string since approximately 90% of all returns did not flow through the blooie line.

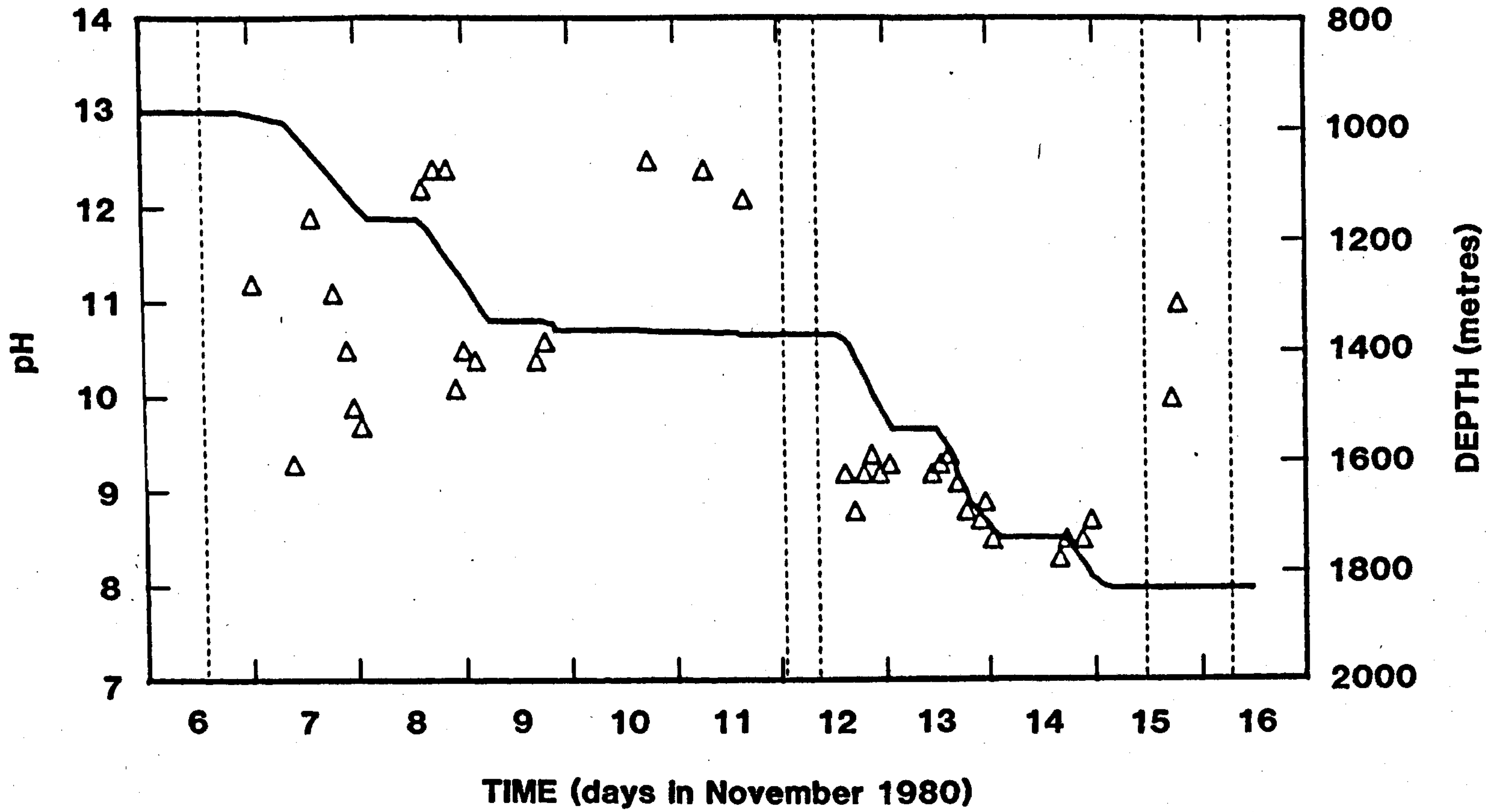


Figure 8. Alkalinity of the Liquid in the Water Line. During phase 2, the pH was specified to be kept between 8 and 9; for the other phases it was to be maintained between 10 and 12.

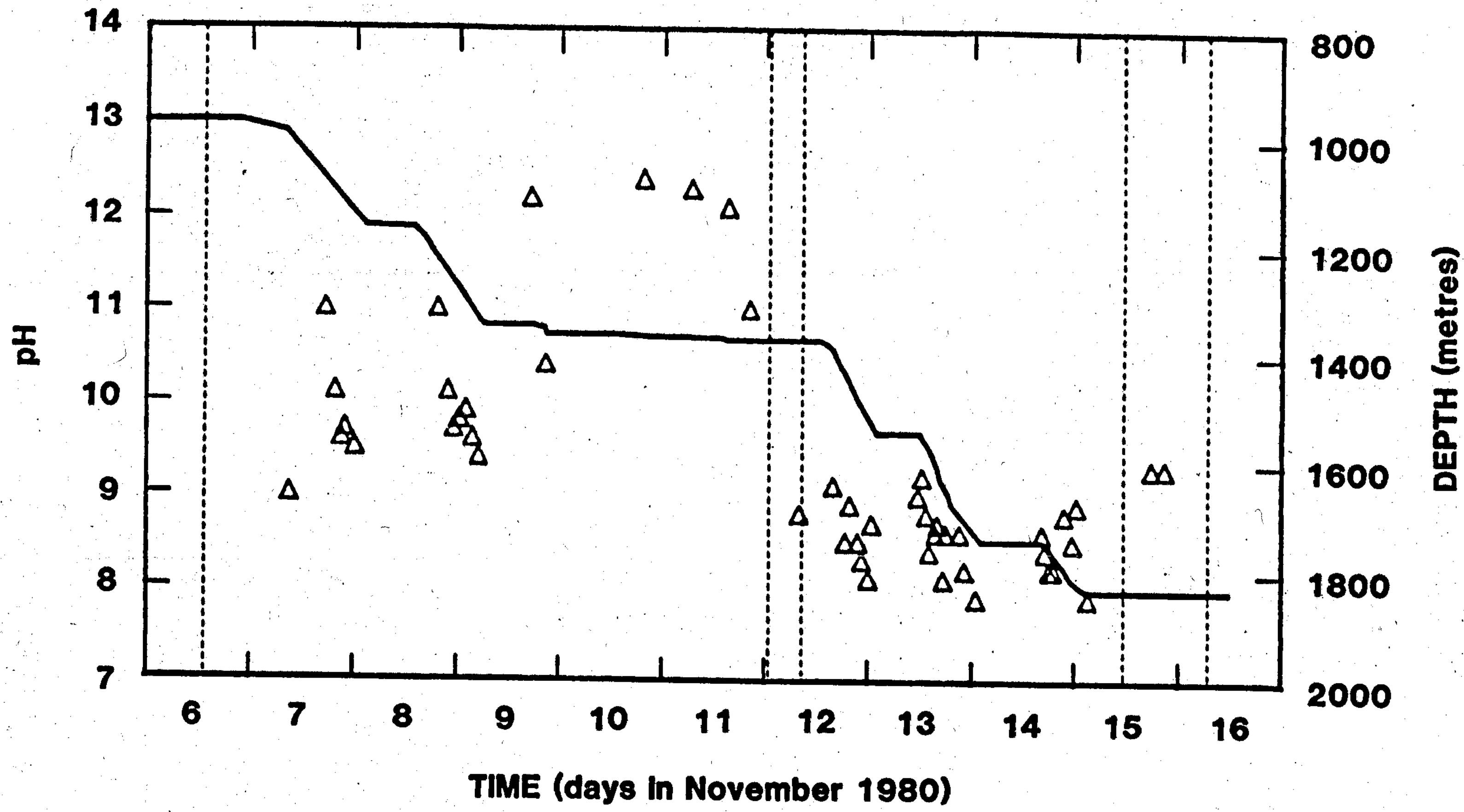


Figure 9. Alkalinity of the Liquid Through the Blooie Line.

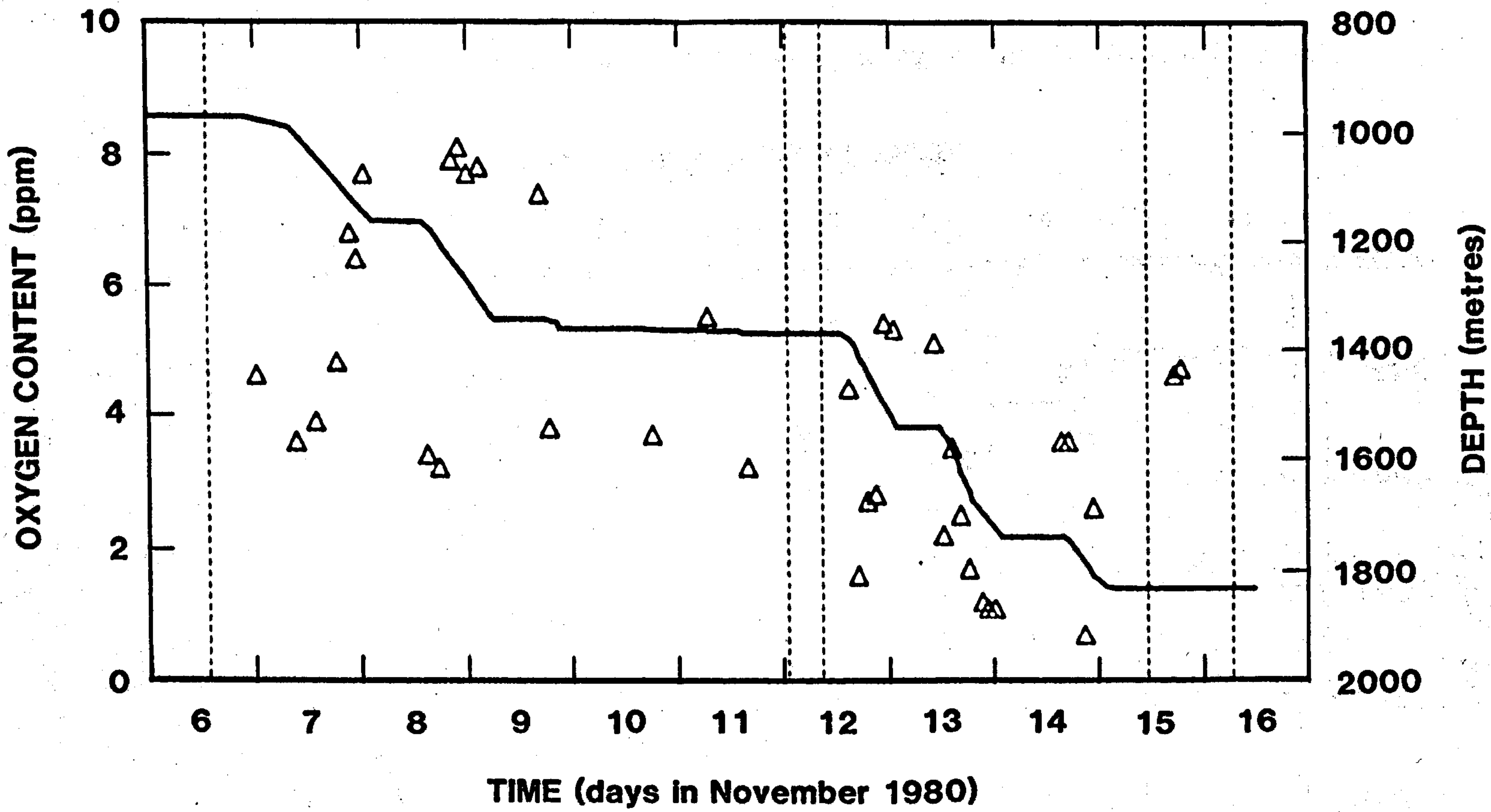


Figure 10. Oxygen Content of the Water Line. These data were taken from liquid samples drawn from the water line, cooled to ambient if necessary and analyzed.

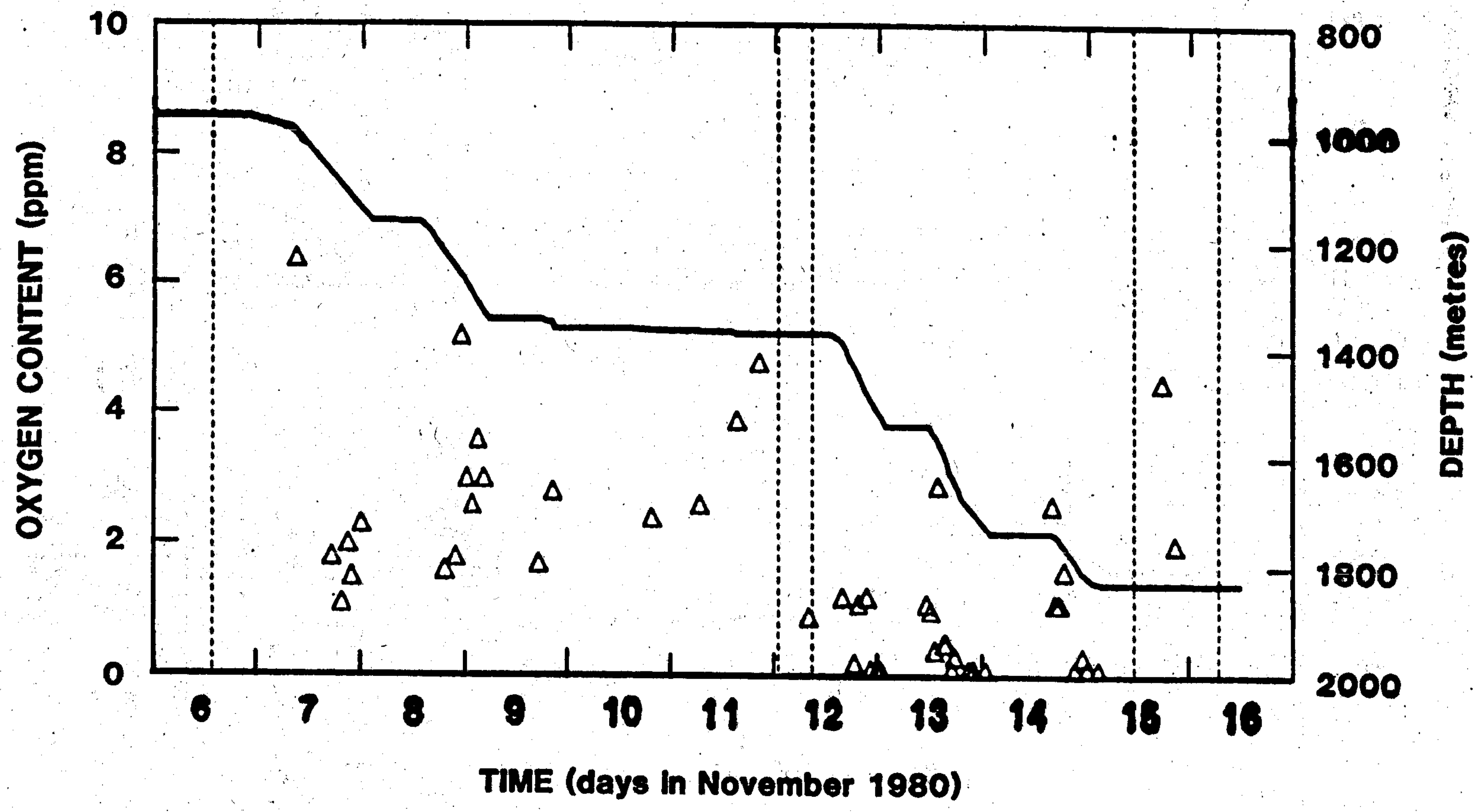


Figure 11. Oxygen Content of the Liquid Returns Through the Blooie Line.

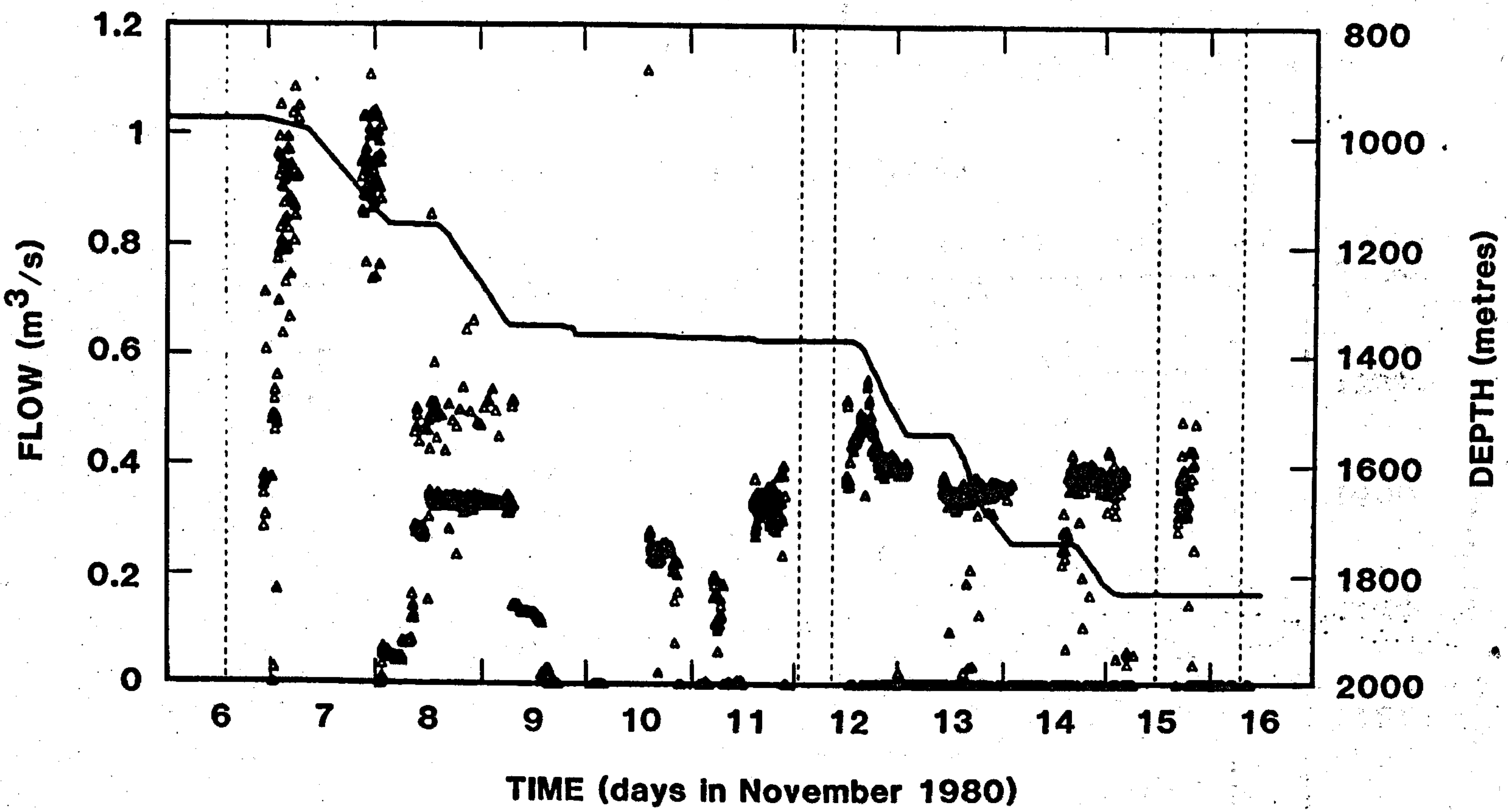


Figure 12. Air or Nitrogen Flow Rate. Data plotted have been adjusted for standard conditions of 15.6°C (60°F) and 101 kPa (14.7 psia).

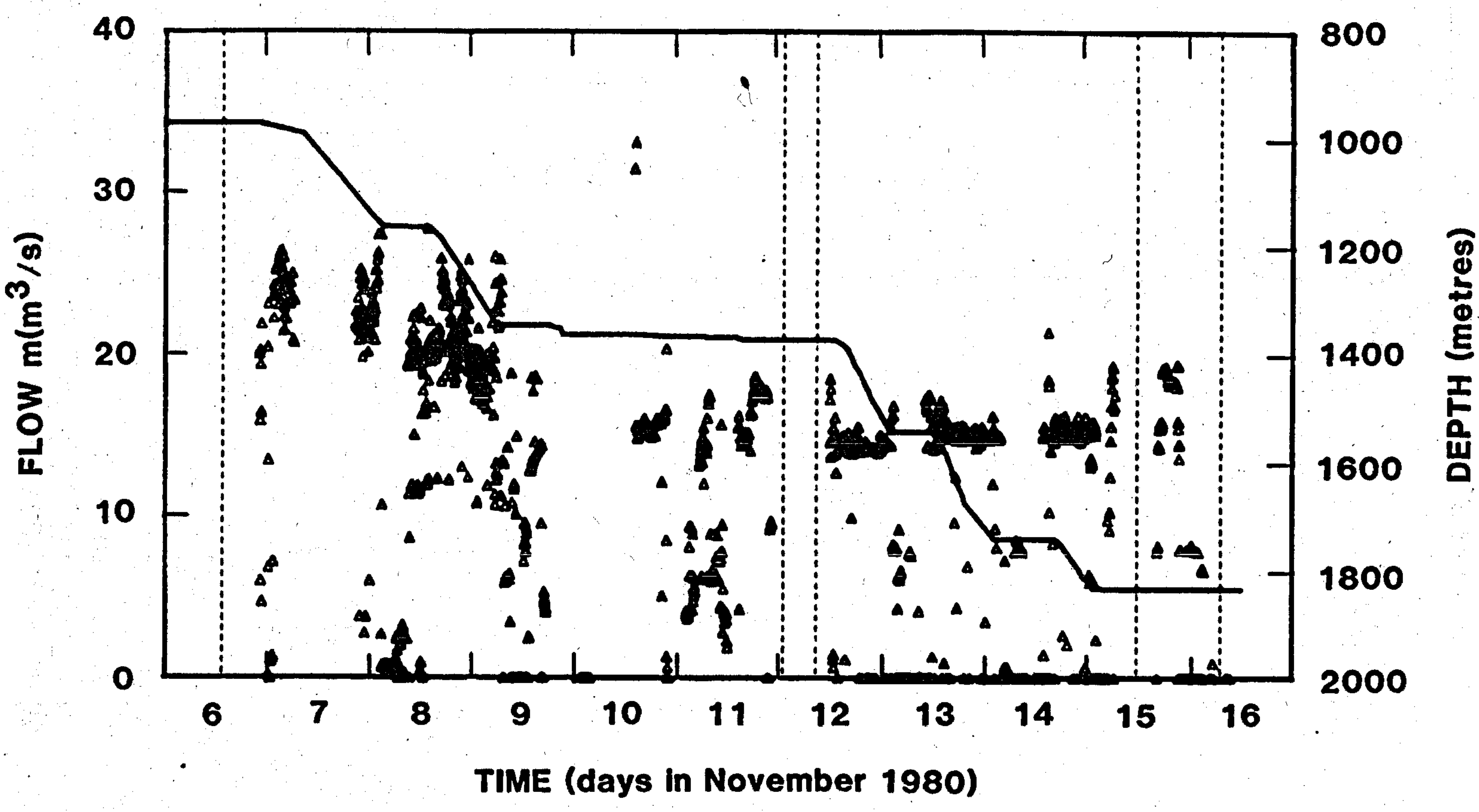


Figure 13. Water Flow Rate. During drilling operations the flow rate was relatively constant.

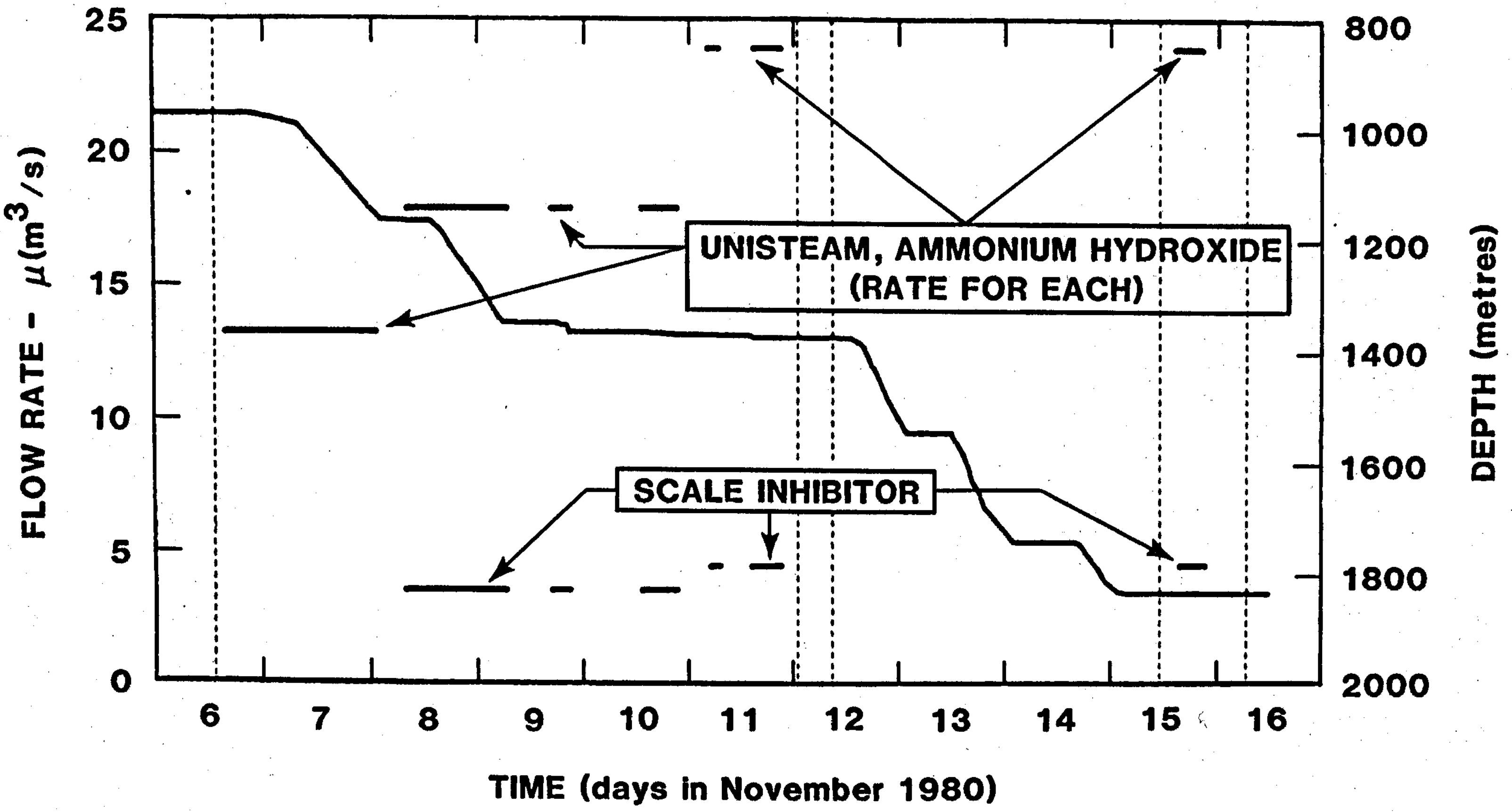


Figure 14. Chemical Injection Flow Rate. Unisteam and ammonium hydroxide were each used at the same rate; H35 Surflo Scale inhibitor was used at a lower rate. No chemicals were injected during phase 2.

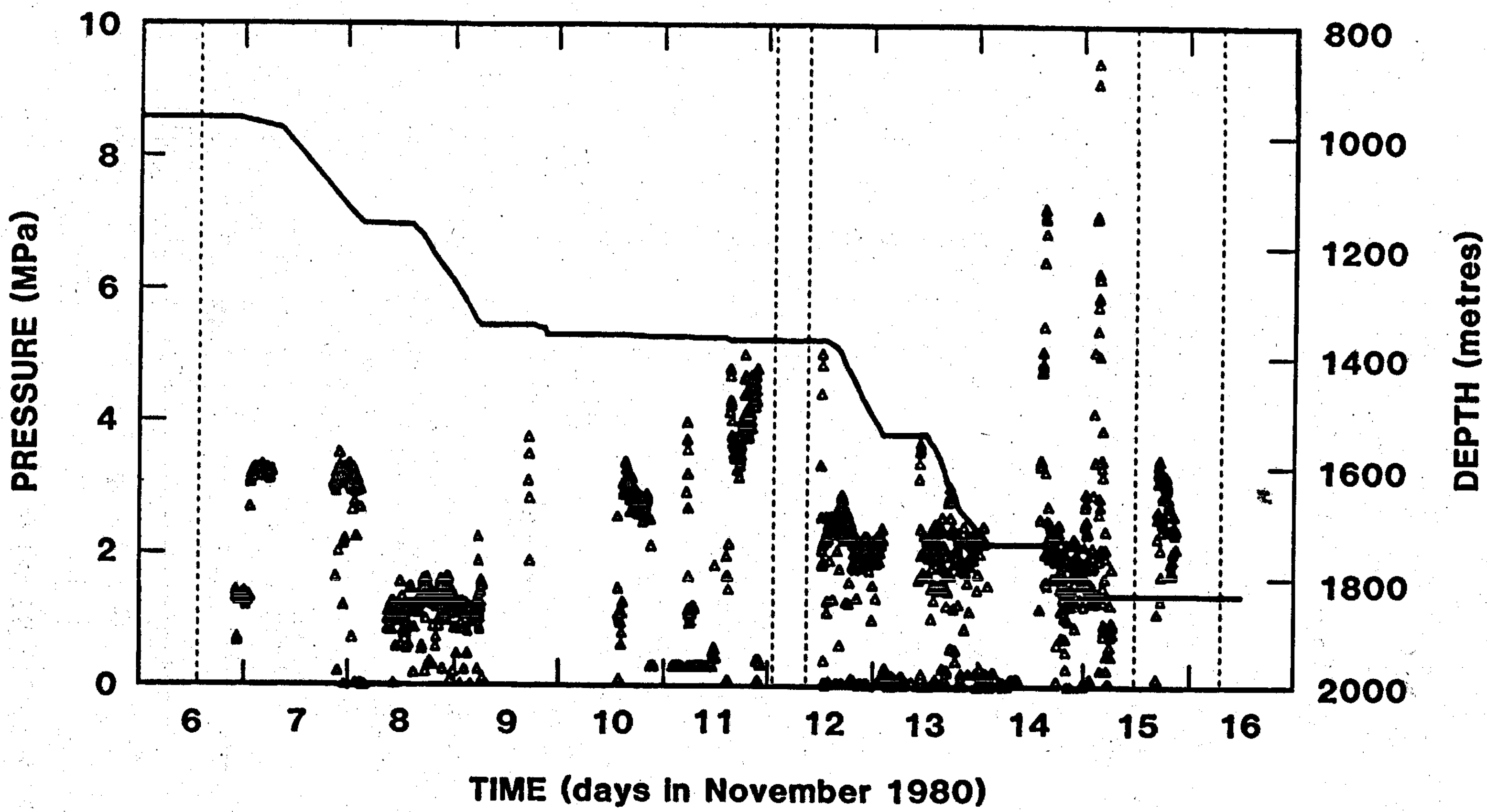


Figure 15. Standpipe Pressure. This data is representative of the data recorded for the air/nitrogen pressure, water pressure and chemical injection pressure since all these lines fed to the standpipe.

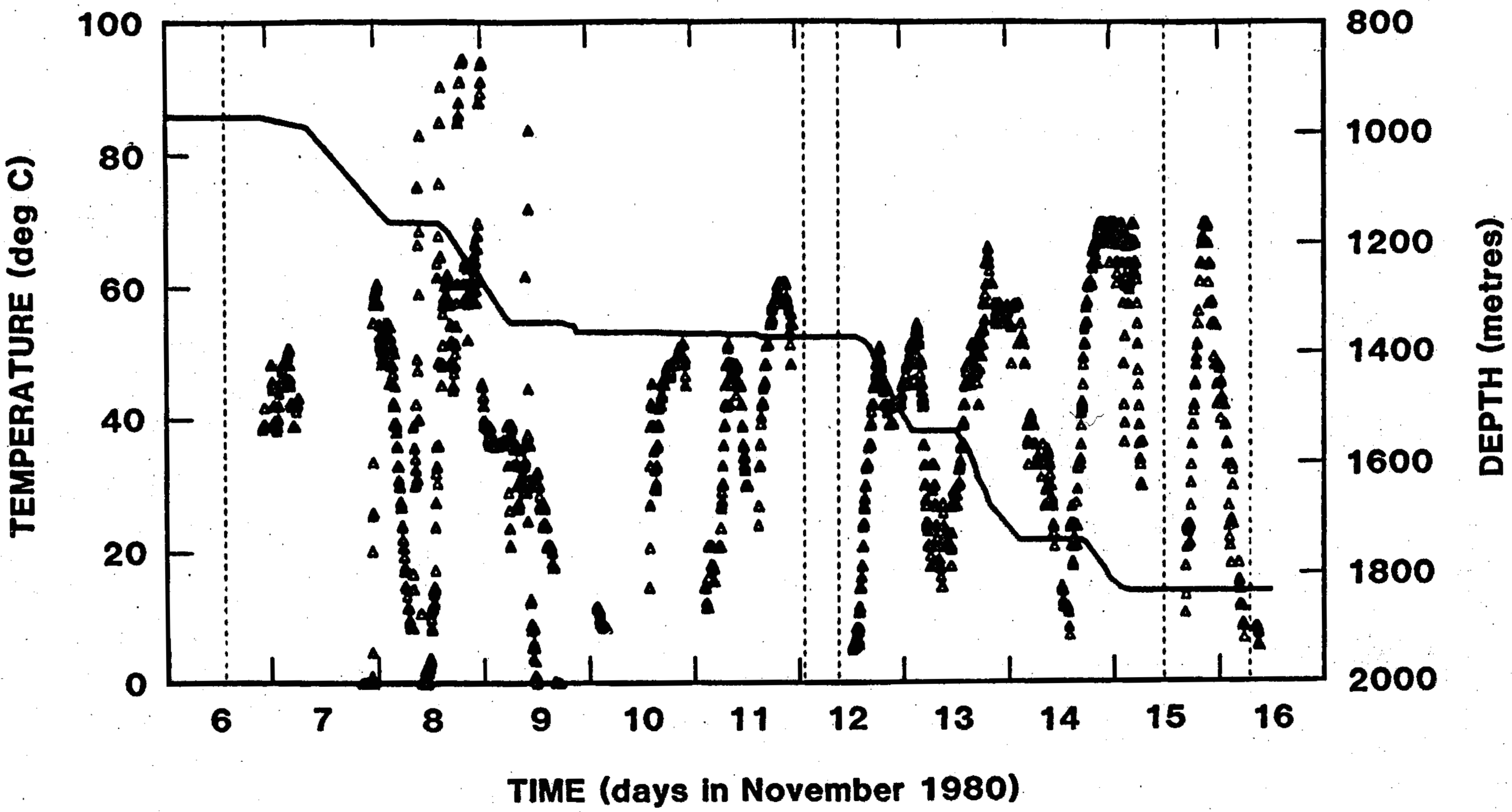


Figure 16. Water Line Temperature. During drilling operations, the water was heated by liquid returns. During non-flowing times this data represents close to ambient air temperatures.

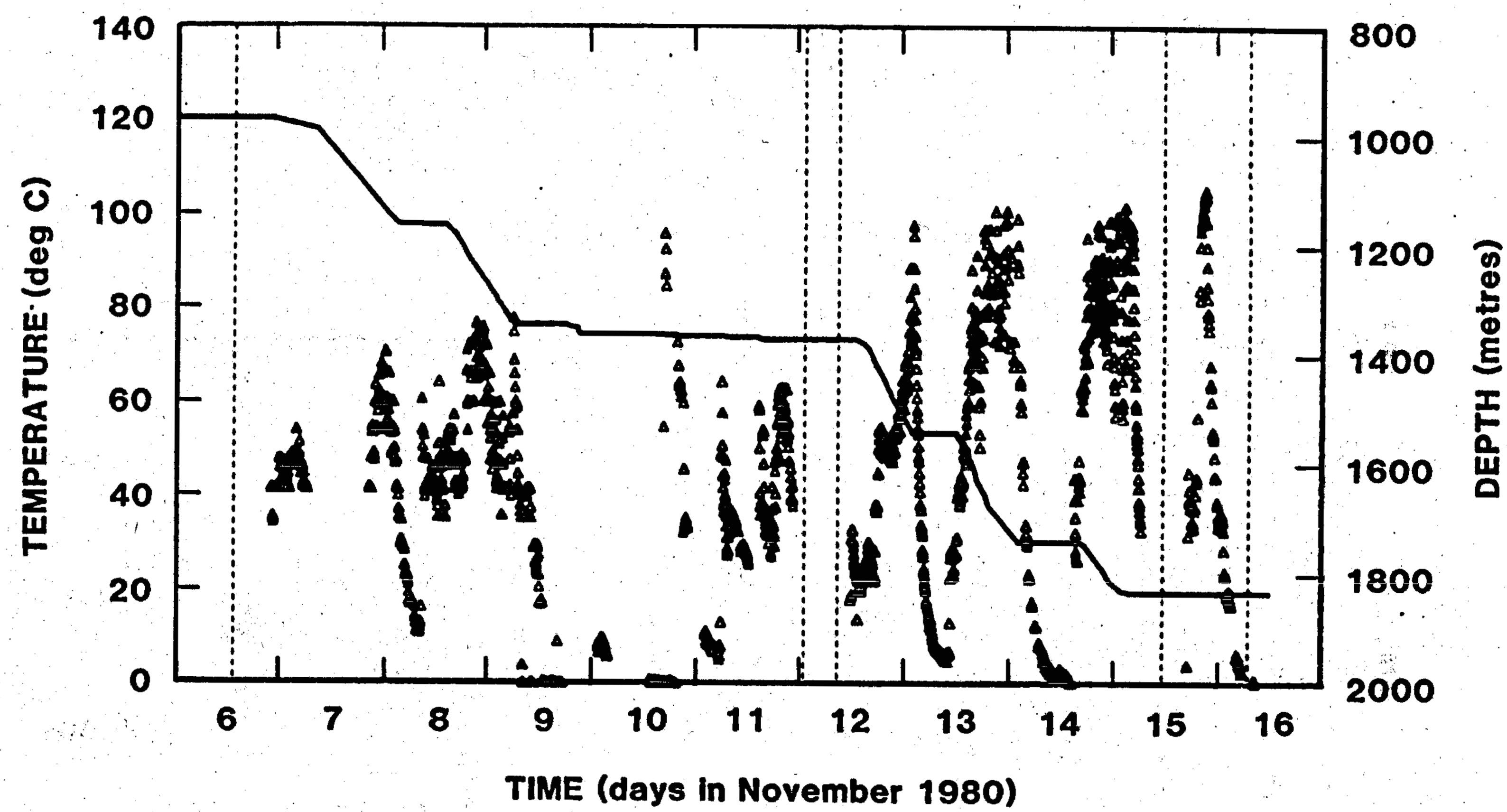


Figure 17. Temperature Measured in the Blooie Line. Since returns flowed through the blooie line only part of the time, these data are not representative of returns' temperature.

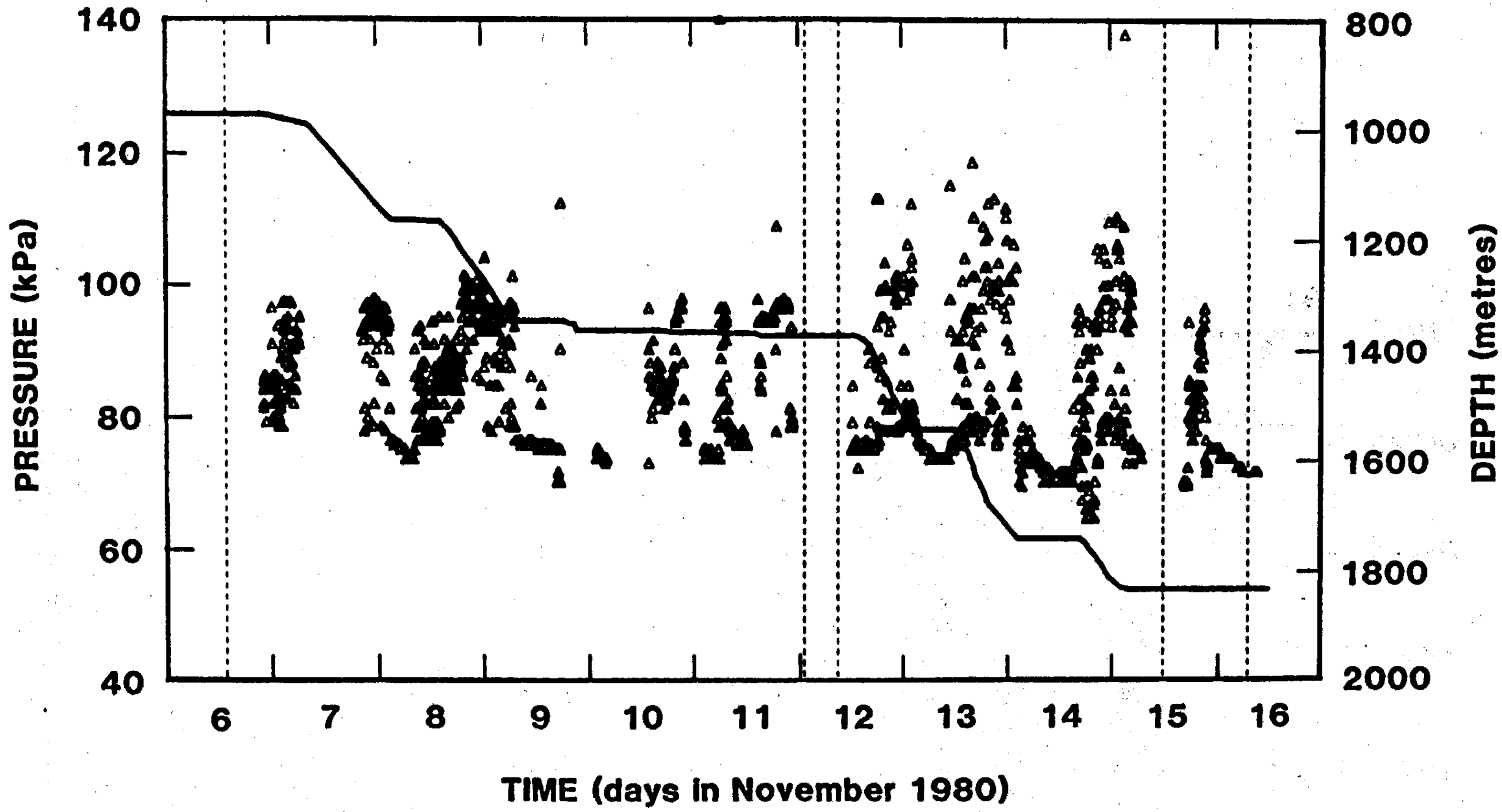


Figure 18. Pressure Measured in the Blooie Line. The ambient pressure at the site was about 69 kPa (10 psi). Pressures above ambient represent times that the blooie line was flowing.